JESSUP

Tests of a Ten-Ton Electric Crane

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TESTS OF A TEN-TON ELECTRIC CRANE

BY

Richard Dale Jessup

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1907

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Arthur Jay Ray

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UNIVERSITY OF ILLINOIS

June 1, 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

RICHARD DALE JESSUP

ENTITLED TESTS OF A TEN-TON ELECTRIC CRANE

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

UNIVERSITY OF ILLINOIS

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OF Bachelor of Science in Electrical Engineering

Morgan Brooks

HEAD OF DEPARTMENT OF Electrical Engineering

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TESTS OF A TEN TON ELECTRIC CRANE.

I - INTRODUCTION.

The travelling crane has come into estensive use only within the last fifteen years, but its introduction has revolutionized methods of manufacture and theory of shop design to a considerable extent. By its use materials of any kind may be quickly transported from place to place in the shop, or finished machinery may be handled in the most expeditious manner, with very little interference with work on the floor.

Much more simple and inexpensive building construction may be used with travelling cranes than is necessary for the proper support of jib cranes, besides, travellers cover much greater space than jib cranes, thus adding materially to their value.

The advantages of a crane for use in the Mechanical Laboratory are, therefore, very easily seen, where machinery is constantly being moved about, where work should obviously be done in the most up to date manner, and where available floor space must all be utilized.

Electric travelling cranes represent the highest development of crane design. This is brought about by the use of independent motors and mechanisms for each movement, by the absence of clutches and speed changing devices and by reducing to a minimum the gearing and other wearing parts, giving, as a result, high efficiency.

The adaptability being unquestioned, it was decided to furnish the Mechanical Laboratory with a travelling crane, which was installed by the Whiting Foundry Equipment Company, in the summer of 1905.

II - PURPOSE OF TEST.

Several points led up to the tests, the results of which form the basis of this paper.

First of all, the crane is a comparatively new piece of apparatus in the laboratory and it was desired to obtain some data concerning its operation. So far as the writers know, no similar tests have been made on travelling cranes. The only tests made by manufacturers are the usual motor tests and a simple lifting test.

Several apparent defects existed in the crane, among them being excessive noise and slow starting, indicating poor starting torque of motors or unusual friction.

The purpose of the test was, therefore, to obtain all possible data concerning the actual operation of the crane under different conditions.

III - DESCRIPTION OF CRANE.

The crane, photographs of which are shown on pages 26-28, has a capacity of 20,000 pounds, with a span of thirty eight feet and bridge travel of about one hundred and thirty feet, and is equipped with three Westinghouse, type F, 400 volts, two phase, variable speed induction motors. The motor which drives the

bridge has a rating of seven and one half horse power, the one on the hoist five horse power, and the trolley motor three horse power.

(a) Features of Construction-

Following is a brief description of the principle features of design and construction, many of which can be seen in the photographs referred to above.

The bridge consists of two single web plate girders, with wide top and bottom flanges to resist lateral stresses. The bridge girders are supported at the ends by trucks built up of structural steel with heavy truck bearings attached. The truck wheels are cast iron and double flanged.

The operator's cab is a frame work of structural steel, containing the switch board, controllers, and resistance irons for the motor circuits.

The motor for bridge travel is located at the end of the bridge, above the cab, and power is transmitted to the drivers through a train of gears and a long shaft.

The trolley supports the entire hoisting and racking mechanisms. Its frame consists of heavy trucks, which are connected by a separator and cross beam carrying an equalizer sheave for the hoisting rope. The mechanism for trolley racking, a diagram of which is shown on page 23, consists of a motor and short gear train, but is not supplied with a brake of any kind whatever.

The hoisting mechanism, shown diagrammatically on page 23 consists of a train of spur gears operated by one of the reversible motors, and driving a right and left grooved drum of sufficient

size to take, without overlapping, the entire length of hoisting rope. By this arrangement the load is always distributed equally between the girders. The drum gear is keyed directly to the drum, thus relieving the shaft of torsion. The electrical brake is of the solenoid type. When hoisting or lowering, sufficient magnetism is developed to release the brake, but when the current is cut off, it is set by means of a heavy spring. The mechanical brake is of the type which depends upon frictional contact to hoist the load. Upon reversing the motor the friction disc is released as fast as the load descends by the action of gravity. This brake is mounted upon a continuous shaft. Lubrication of all bearings is obtained by means of grease cups.

Current is spppplied to the crane switchboard by shoes sliding upon four copper wires supported by porcelain insulators along the wall immediately below the track. The sliding contact method is also used in distributing current from the switchboard to the trolley and hoist motors. The wires in this case are situated on the innerside of the bridge girders. Current for the bridge motor is taken directly from the switch board.

(b) Motors-

An induction motor is a constant field machine, and tends, therefore, to run at constant speed. With a given rotor resistance the motor will produce a given torque at a certain speed but, if the resistance of the rotor circuit is increased, the secondary current, and consequently the torque, will be decreased and the motor will tend to slow down. As the speed of

the motor drops, that of the revolving field, relative to the rotor, increases, thus increasing the secondary current and the torque. When the speed has become low enough the original torque will be developed and the motor will again run at a steady speed. If sufficient resistance is introduced into the rotor circuit the maximum torque is developed at stand still, thus making this type of motor very suitable for travelling cranes, as they require the greatest torque at starting. These motors have much the same characteristics as a direct current series motor except that their maximum speed is limited by synchronism. The power factor of these motors is the same for a given torque independent of the speed. At constant torque, the efficiency varies approximately as the speed.

The Westinghouse, typeF, motor differs from the ordinary induction motor in that the secondary, instead of being of the squirrel cage type, is wound like the rotating member of a three phase rotating armature generator, and carries three slip rings and brushes. The variable speed is obtained by inserting variable resistance between the collector rings of the rotor, as described above.

The controller for each motor consists of a drum switch, a diagrammatic development of which is shown on page 25 . The line wires, field terminals and resistance terminals are carried to stationary brushes at the sides of the controller. .These make contact with short circuiting connectors on the shaft of the controller when the handle is rotated. The controller reverses by simply rotating the handle in opposite directions. When the

controller handle is placed on the first point the field circuits are closed with the line by the stator contact blocks. On the next point the rotor circuit is closed through a resistance and on each succeeding one a portion of the resistance is short circuited until the last point is reached, when the rotor is entirely short circuited. Upon rotating the controller handle in the opposite direction, the same series of operations is repeated, except that one phase of the stator is reversed, thus reversing the direction of rotation of the motor.

IV - INSTRUMENTS USED IN TEST.

The instruments used in the test were an indicating wattmeter and a voltmeter for measuring the power input, speed counter, watch, etc. The weights used consisted of a car truck suspended by chains and loaded with various amounts of pig iron and scrap.

V - MANNER OF CONDUCTING TEST.

The first step of the test was to obtain the principle dimensions of the crane, gear ratios for the bridge, trolley and hoist, and diameters of truck wheels, hoisting drum, and rope. The diameter of the truck wheels was obtained by measuring the distance travelled along the track for a certain number of revolutions. It will be seen that with these data the speed of hoisting and of bridge travel could be easily found by taking the R. P. M. of the respective motors. This was done in the test.

The car truck and a small rotary engine, which were used as a foundation for the load, were hauled to the Agricultural Department scales and weighed. These were attached to the crane hook by four heavy chains and further weight, consisting of pig iron, was added as required. The heaviest load, of 20,000 pounds, is shown in the photograph on page 28 . During the test loads of 4000, 8000, 12,000, 16,000, and 20,000 pounds were used. One wattmeter was used, and as the circuit was two phase, the readings had to be multiplied by two to give the total input. The wattmeter and voltmeter were connected to the switchboard in the operator's cab, with a short-circuiting switch across the wattmeter.

Two operators were required to conduct the test, one stationed at the motor and the other in the cab. The former took R. P. M. after the motor had reached constant speed. The duties of the latter were more complex. After closing the short circuiting switch across the wattmeter he started the crane and, when it had come up to speed, opened the switch and took the readings of the wattmeter and voltmeter. At a signal from the man above, the crane was stopped and the process repeated in the opposite direction. These readings were taken for loads from zero to 20,000 pounds, as mentioned above, for all controller points and both directions of bridge travel. Similar data were taken for hoisting and lowering. The trolley was in the center of the bridge for all readings. No readings for trolley travel were taken, for reasons which will be explained later. The deflection of the bridge for the maximum load was obtained by measuring the

distance from the trolley to a roof truss, and was found to be eleven sixty-fourths of an inch.

VI - CURVES.

It was thought best to show the results of this test by a series of curves and, in order to do this, a few calculations were necessary. All R. P. M. of motors were reduced to speed in feet per minute of bridge or hook travel. For a final result in the series for bridge travel, East and West readings were averaged for each load and each controller point. Efficiency of hoisting was calculated by dividing the power of raising the load by the input of the motor. From these data the following curves, shown on pages 16 - 22, were plotted: first, curves between controller points and speed for hoisting, lowering and bridge travel; second, curves between power and speed for hoisting, lowering and bridge travel; and third, curves between speed and efficiency for hoisting.

VII - DISCUSSION OF CRANE.

(a) Criticism of Construction.

Several questionable features of the crane are noticeable upon close examination. Most prominent of these is the excessive noise of the gear train in moving the bridge and, to a less extent, in hoisting. The first of these defects may be attributed to improper alignment of shafts and incorrect meshing of gears, the latter being especially noticeable in the motor pinion. In the hoisting mechanism the noise was probably due mostly to the length of the gear train. A feature of the crane which might be criticised is the absence of a brake on the trolley. This is very inconvenient, due to the fact that the trolley attains such a speed with the motor running only on the first controller point that it is frequently necessary

to reverse in order to stop the motor. It would seem that if the trolley is not to be equipped with a brake, a better speed control should be provided. This lack of control, added to the fact that the distance of travel was so short, made it impossible to obtain any data concerning the trolley, because the power could not be left on long enough for readings to be taken. Another criticism of the crane which would, however, apply more particularly to cranes of greater capacity and longer spans than this one, is the arrangement of the main driving shaft for bridge travel. This is shown in the photograph and in the diagram, page 24. As the driving force is applied near one end of the shaft, the torsion in it causes one end to lag slightly behind the other in starting. With long spans and heavy loads this might become so great as to cause undue strains in the crane and excessive flange friction.

(b) Defects in Operation-

Three defects were noticeable in the operation of the crane. Usual specifications for this size of crane call for a hoisting speed of ten to twenty feet per minute, but the highest speed attained in the test was slightly over six feet per minute. This causes an undue waste of time in a hoist of any considerable length. The second fault of which it was impossible to determine the cause, applied to the bridge motor. In several instances it seemed that one phase became inactive for some reason. This was indicated by a very large increase in the power consumed by the other phase and by a marked decrease in speed. This occurred principally with the heavier loads and only on controller points four and five. A close examination of the motor circuit, and especially of the controller, for defective contacts, failed to

reveal the cause of this trouble. Again, a variation of power was noticeable, it being greater at either end of the track than near the centre. This was probably due to poor alignment of the track, causing variation in flange friction.

VIII - DISCUSSION OF DATA AND CURVES.

A comparison of the hoisting and lowering curves between controller points and speed indicates that the speed of lowering is very little greater than for hoisting. Ths curves for hoisting approach the same speed for the last controller point, but differ greatly for the lower points. This is because the speed regulation of the motors is impaired by the insertion of resistance in the rotor circuit. In lowering, the curves all intersect near the fifth controller point, the speed being greater for the heavier loads than for the lighter ones on the last point. This would seem to indicate a critical point in the action of the mechanical brake, on either side of which its behavior is different. This is more strongly shown by the curves between speed and power on page 20 . Here, the critical point comes between the 8000 and 12,000 pound loads, the relative power above this point being greater and below less. As the brake was not taken apart and examined in detail, no definite reason could be assigned for its action.

The curves for bridge travel also approach a single point for high speed but do not show so much variation as the hoisting curves for the lower speeds.

The curves between speed and power for hoisting and bridge travel are practically straight lines, with nearly constant power for a given load. This is accounted for by the fact that the motors have a decreased efficiency at lower speeds.

The efficiency curves on page 22 are what would be expected of a mechanism of heavy construction and relatively large friction. They show a higher efficiency for the heavier loads. This is caused to a limited extent, by the motor itself, but to a much greater degree by the friction losses of the mechanism, which vary but slightly for the different loads.

IX - CONCLUSIONS.

To sum up, the conclusions regarding the points of construction and of operation of the crane are as follows:

(a) There is excessive noise of gearing, especially on bridge.

(b) Absence of brake on trolley racking mechanism is inconvenient.

(c) Location of bridge motor at the end is not best design.

(d) Speed of hoist is too low.

(e) There is probably a faulty contact or connection in the bridge motor circuit.

(f) Variation in power for driving bridge is noticeable, probably due to poor alignment of track.

(g) Efficiency of hoist is much higher for the heavier loads than for lower ones.

(h) The action of the mechanical brake can not be explained. It is probably out of adjustment.

(i) Friction of the crane was large, as would be expected of a machine of heavy construction, subject to various twisting and bending forces, which would tend to throw the shafting out of alignment and in other ways increase friction.

Tests of a Ten Ton Electric Crane.

Built by Whiting Foundry Equipment Co.

R.D. Jessup and A.J. Ray. May, 1907.

Hoisting.

Load.	Controller Point No.	Speed Ft. per Min.	K.W.	Volts.	% Eff.
0	1	3.80	1.48	458	
	2	4.60	1.56	456	
	3	4.95	1.60	460	
	4	5.41	1.60	458	
	5	5.63	1.68	462	
	6	5.87	1.60	460	
4000#	1	2.30	2.08	456	10.0
	2	3.32	2.16	456	13.9
	3	4.37	2.20	460	18.0
	4	5.18	2.28	458	20.6
	5	5.63	2.32	460	21.9
	6	5.98	2.36	456	22.9
8000#	1	1.03	3.00	460	6.2
	2	2.65	3.00	452	16.0
	3	3.45	3.04	450	20.5
	4	4.54	3.08	454	26.7
	5	5.30	3.08	456	31.1
	6	5.92	3.16	452	33.9
12000#	3	2.65	4.16	456	17.3
	4	4.37	4.28	456	28.2
	5	5.29	4.36	464	32.9
	6	5.98	4.52	464	35.9
16000#	3	2.53	4.72	472	19.4
	4	4.26	4.88	472	31.5
	5	5.29	5.00	472	38.3
	6	5.98	5.12	470	42.4
20000#	3	1.67	5.28	460	14.3
	4	3.68	5.52	460	30.1
	5	5.18	5.68	468	41.2
	6	5.98	5.76	474	46.8

Tests of a Ten Ton Electric Crane.
Built by Whiting Foundry Equipment Co.
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Lowering.

Load	Controller Point No.	Speed Ft. per Min.	K.W.	Volts.
0	1	3.91	1.48	456
	2	4.48	1.52	460
	3	5.06	1.60	462
	4	5.41	1.68	464
	5	5.63	1.68	462
	6	5.98	1.60	456
4000#	1	3.32	1.80	456
	2	4.37	1.72	454
	3	4.95	1.72	460
	4	5.52	1.68	460
	5	5.75	1.60	464
	6	5.98	1.60	456
8000#	1	1.55	2.08	456
	2	2.99	2.00	452
	3	4.32	1.96	452
	4	5.18	1.92	452
	5	5.63	1.84	452
	6	6.10	1.68	460
12000#	3	3.68	3.28	458
	4	4.95	3.44	458
	5	5.75	3.56	464
	6	6.21	3.60	464
16000#	3	3.45	3.78	472
	4	4.83	3.84	472
	5	5.63	4.00	472
	6	6.21	4.16	472
20000#	3	3.50	3.60	468
	4	4.83	3.84	472
	5	5.46	4.24	464
	6	6.21	4.64	468

Tests of a Ten Ton Electric Crane.
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Bridge Travel.

Load	Controller Point No.	Speed Ft. per Min.	K.W.	Volts.
0	2	83.6	3.36	458
	3	132	3.60	460
	4	182	3.68	464
	5	205	3.76	464
	6	217	3.84	452
4000#	2	63.8	3.60	456
	3	117	4.00	452
	4	165	4.16	452
	5	198	4.32	452
	6	216	4.40	452
8000#	3	110	4.24	452
	4	153	4.48	456
	5	200	4.64	456
	6	219	4.72	456
12000#	3	97.2	5.12	464
	4	160	5.28	472
	5	196	5.40	468
	6	218	5.52	468
16000#	3	82.6	5.92	476
	4	152	6.16	476
	5	193	6.24	456
	6	219	6.40	460
20000#	3	52.0	6.24	452
	4	116	6.40	468
	5	186	6.64	460
	6	215	6.72	456

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Tests of a Ten Ton Electric Crane.
Curves Showing
Relation Between Controller Points and Speed
Hoisting Load
— by —
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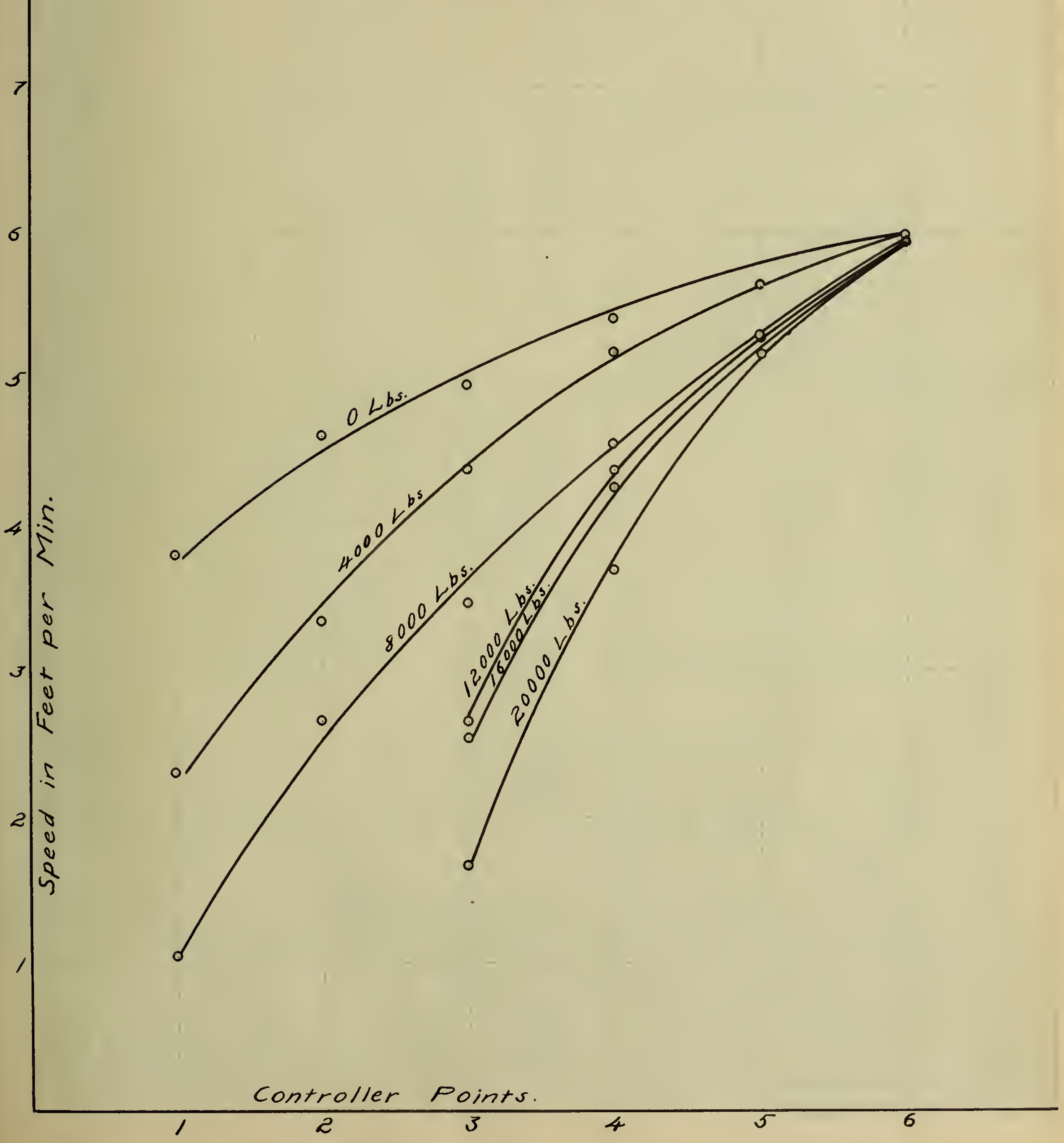

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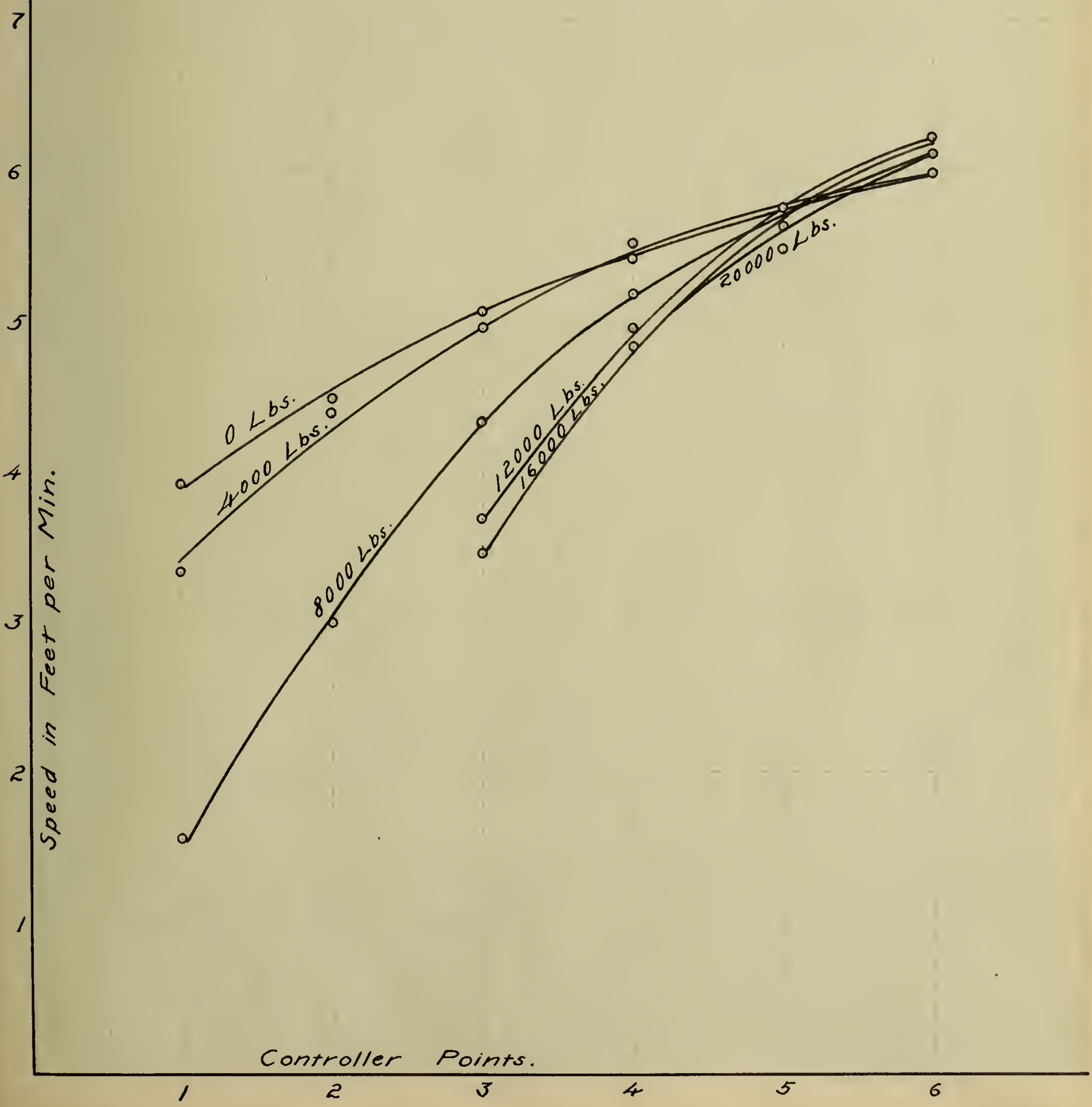

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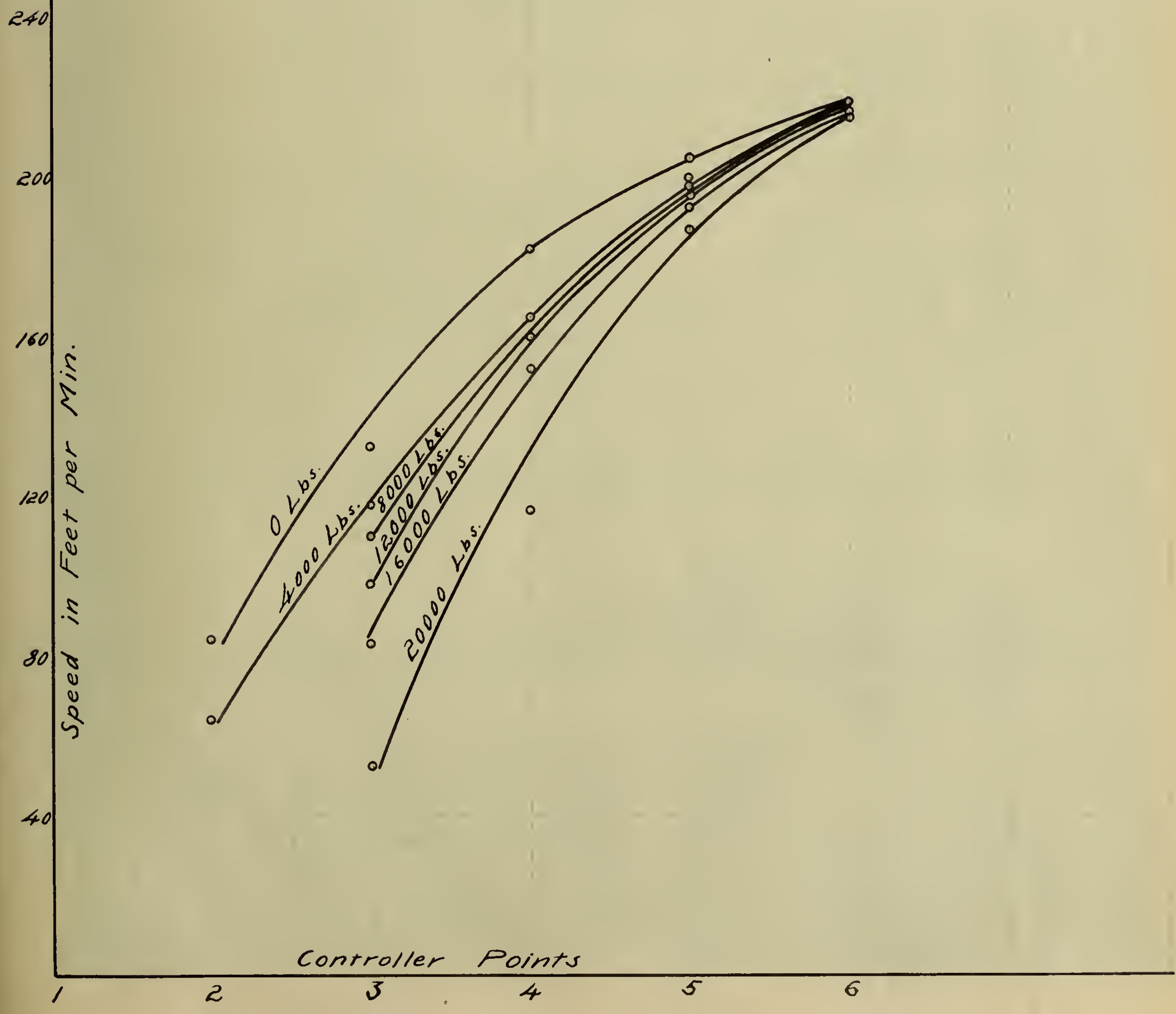

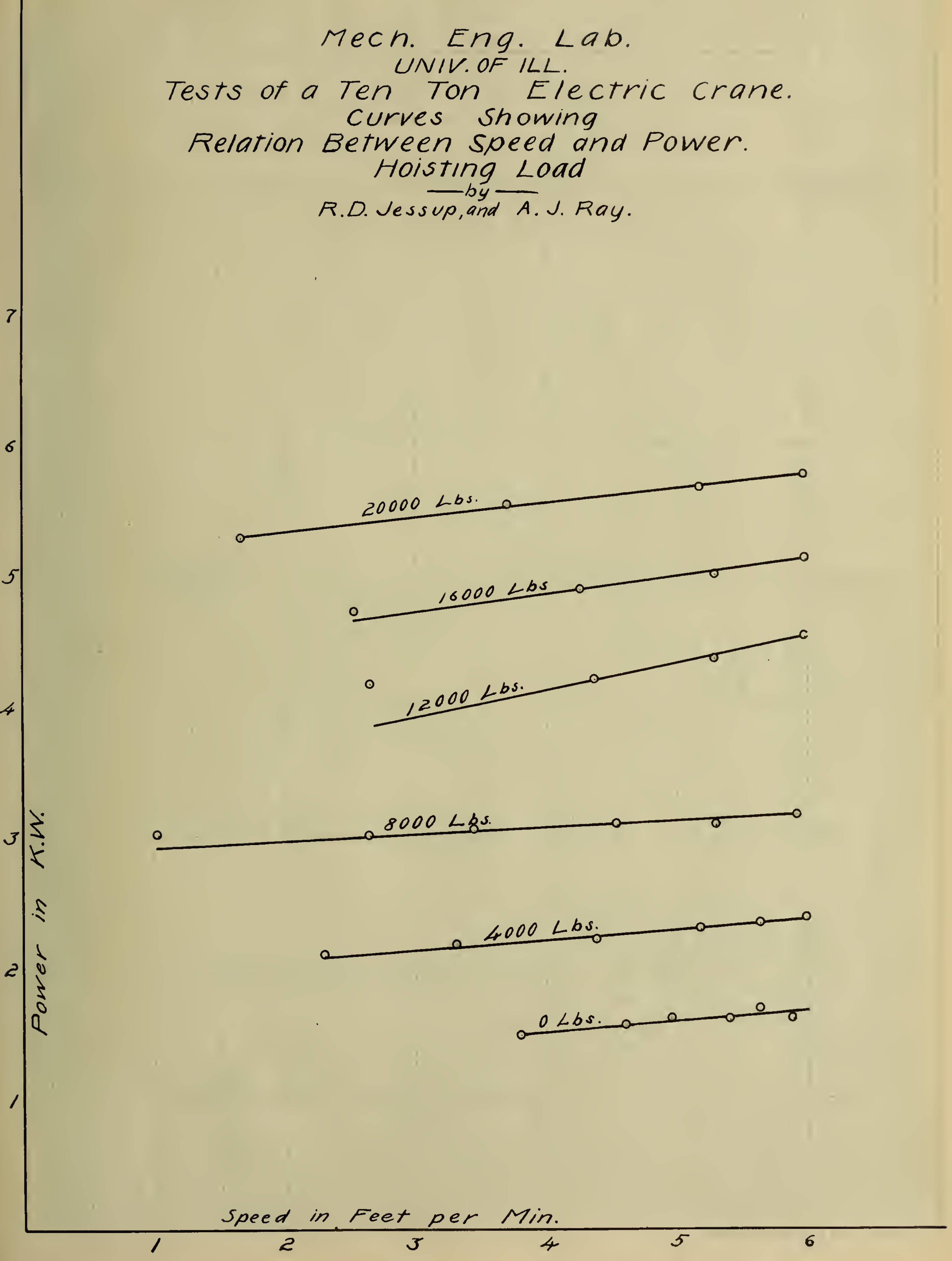
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R.D. Jessup, and A. J. Ray.
20000 Lbs.
16000 Lbs
12000 Lbs.
8000 Lbs.
4000 Lbs.
0 Lbs.
Power in K.W.
Speed in Feet per Min.
1
2
3
4
5
6
7

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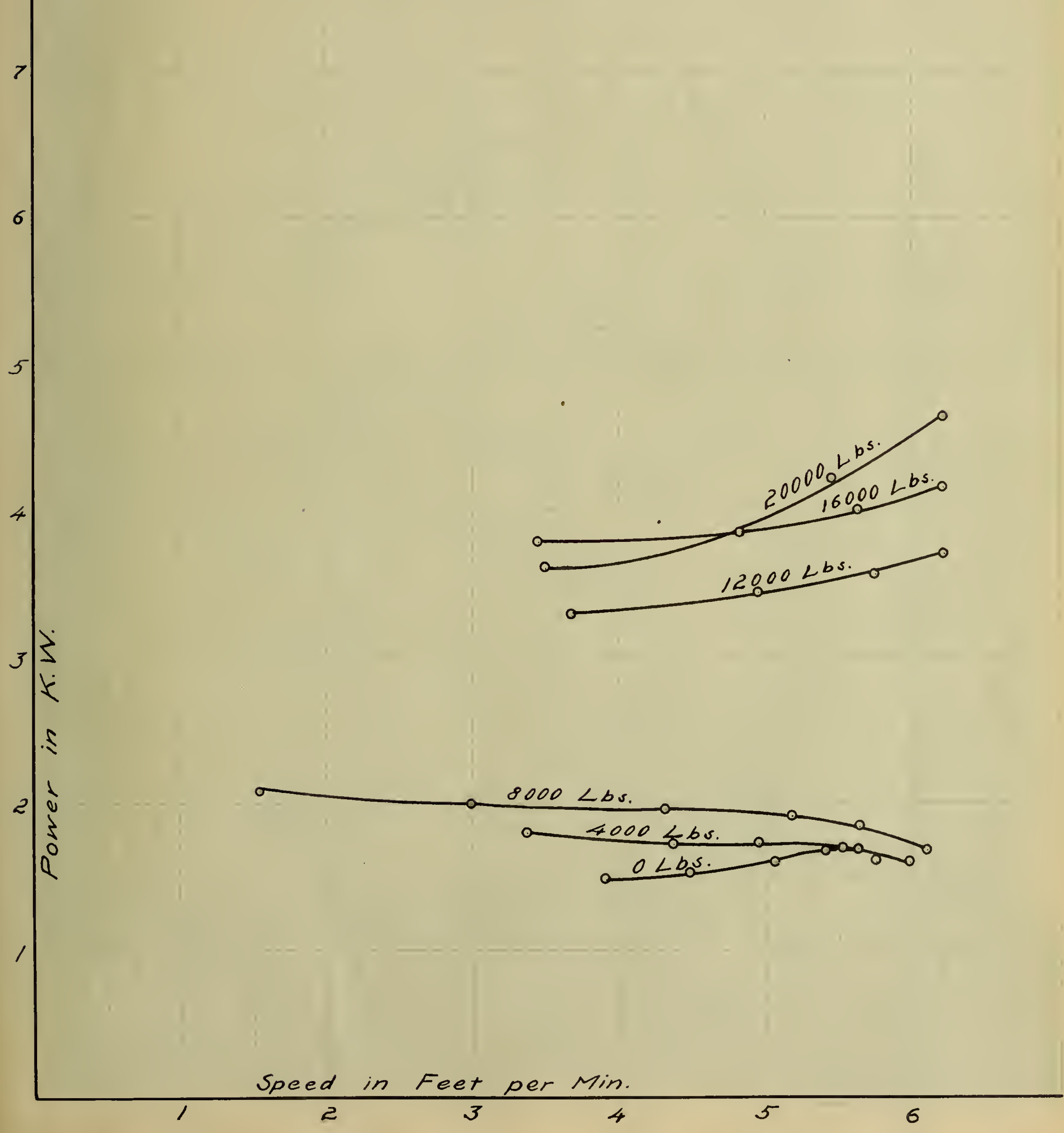

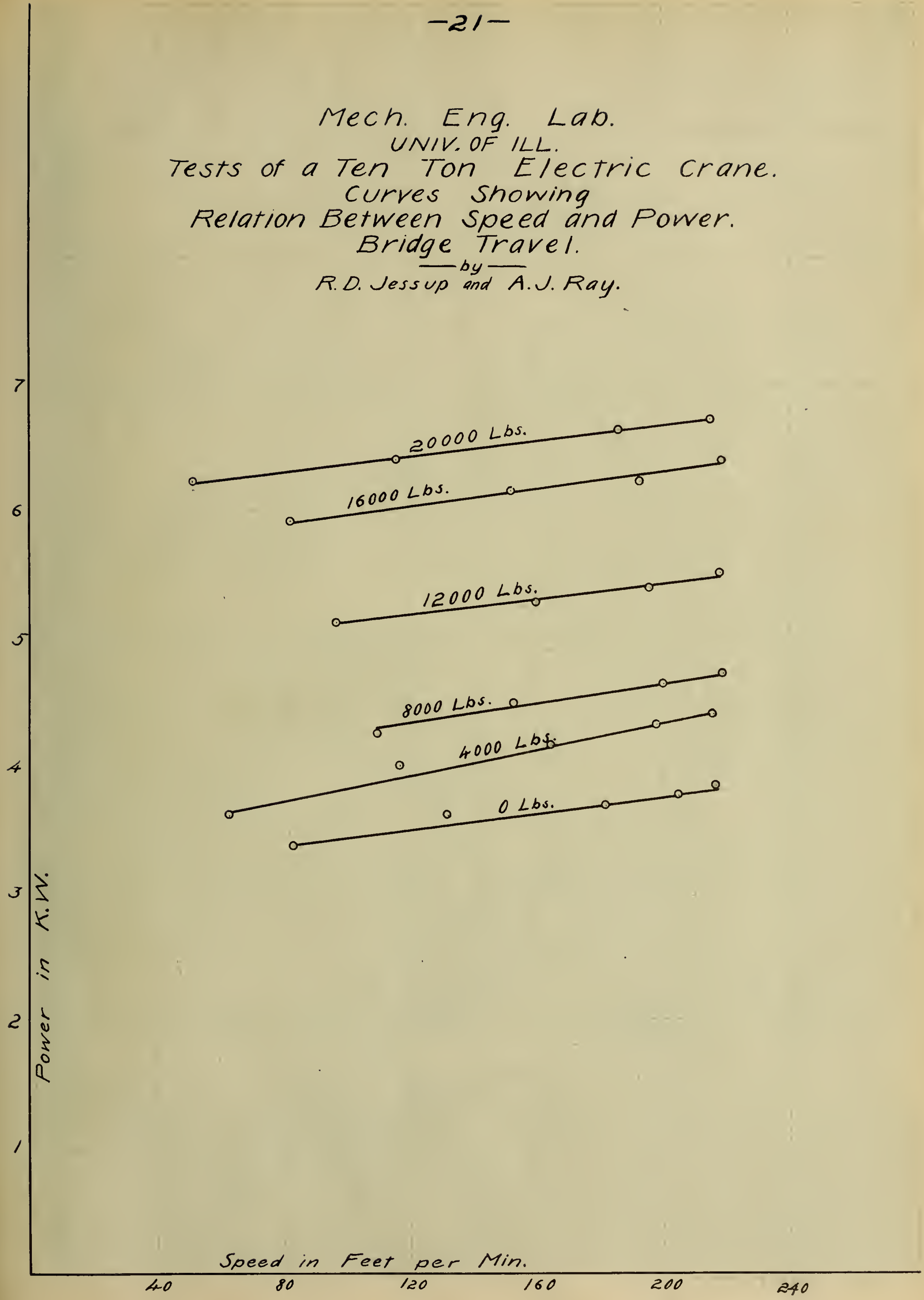
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Bridge Travel.
—by—
R. D. Jessup and A. J. Ray.
20000 Lbs.
16000 Lbs.
12000 Lbs.
8000 Lbs.
4000 Lbs.
0 Lbs.
Power in K.W.
7
6
5
4
3
2
1
Speed in Feet per Min.
40
80
120
160
200
240

Mech. Eng. Lab.
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Tests of a Ten Ton Electric Crane
Curves Showing
Relation Between Speed and Efficiency.
Hoisting Load.
—by—
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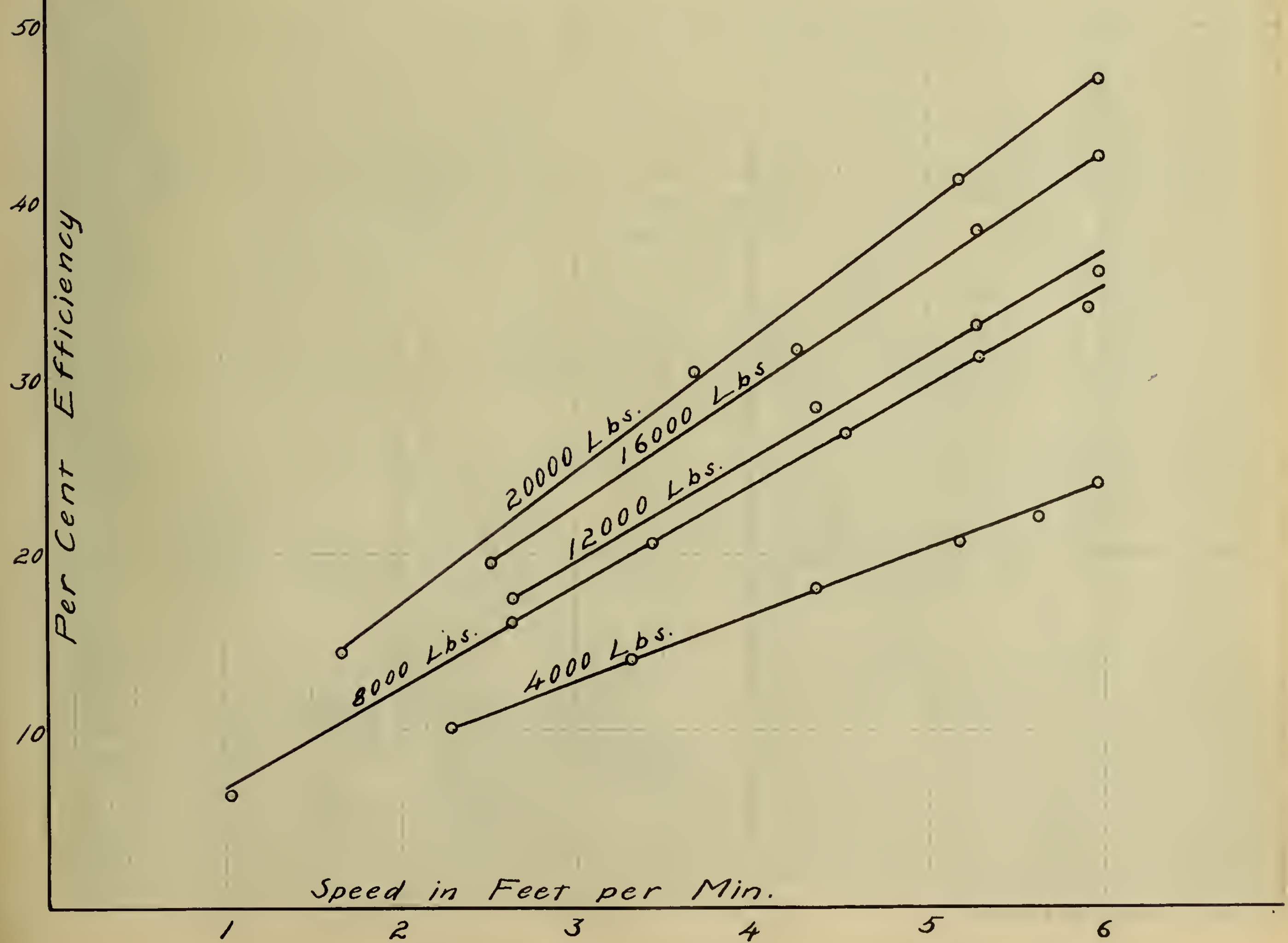


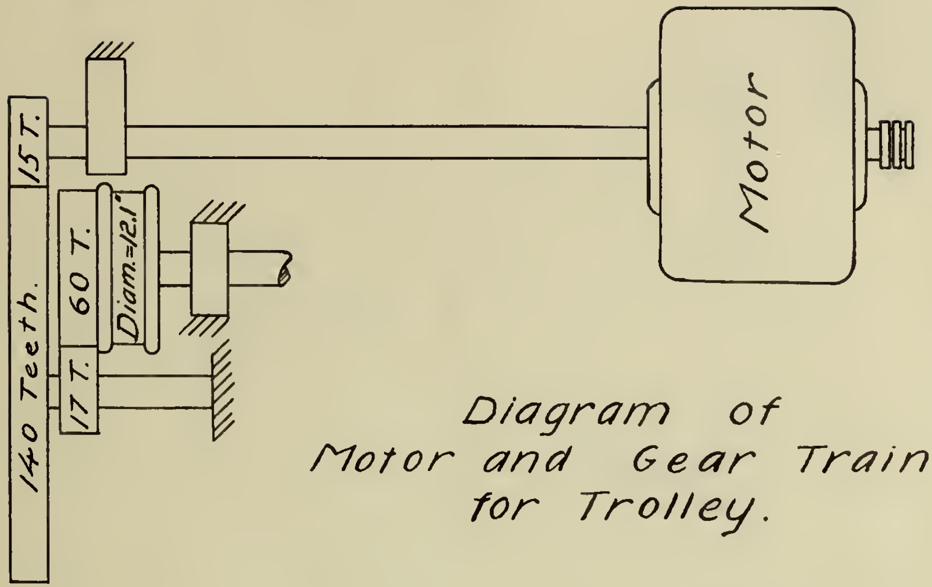


Diagram of
Motor and Gear Train
for Trolley.

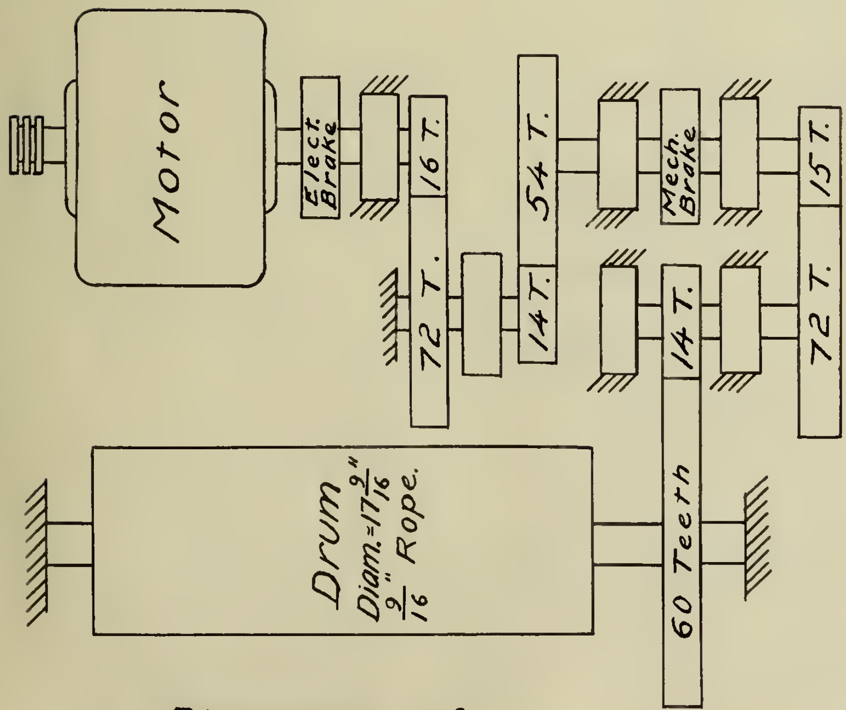


Diagram of
Motor and Gear Train
for Hoist.

Diagram of
Motor and Gear Train
for Bridge.

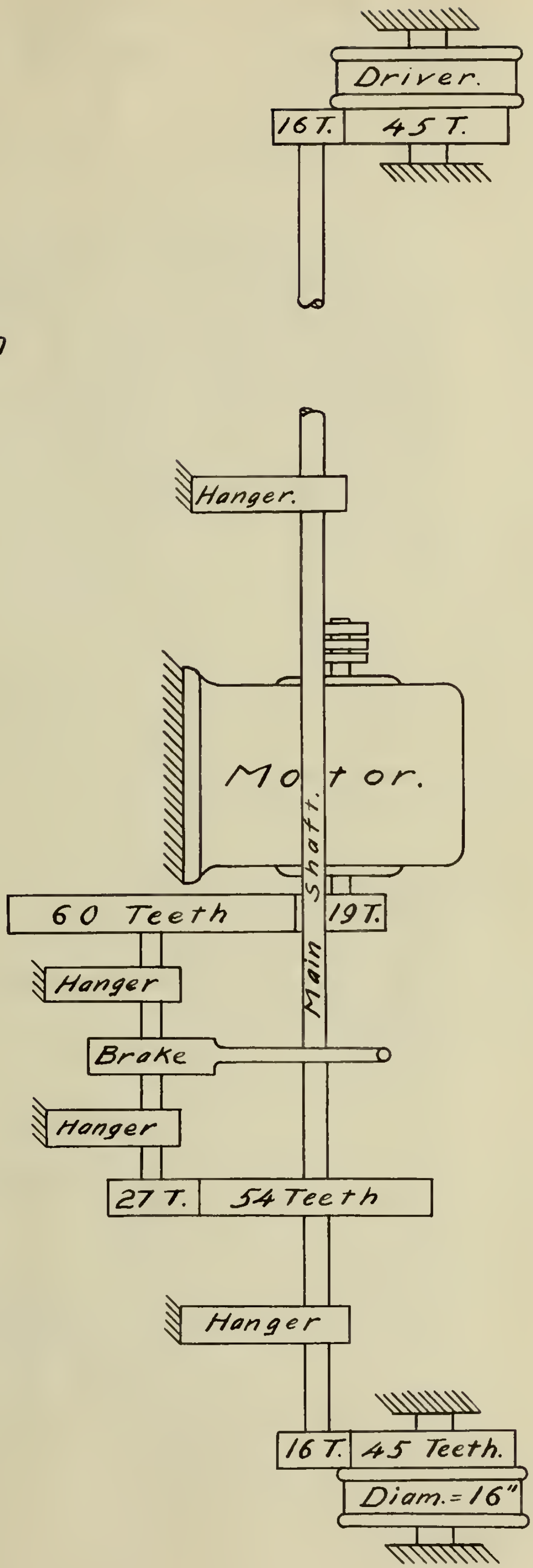
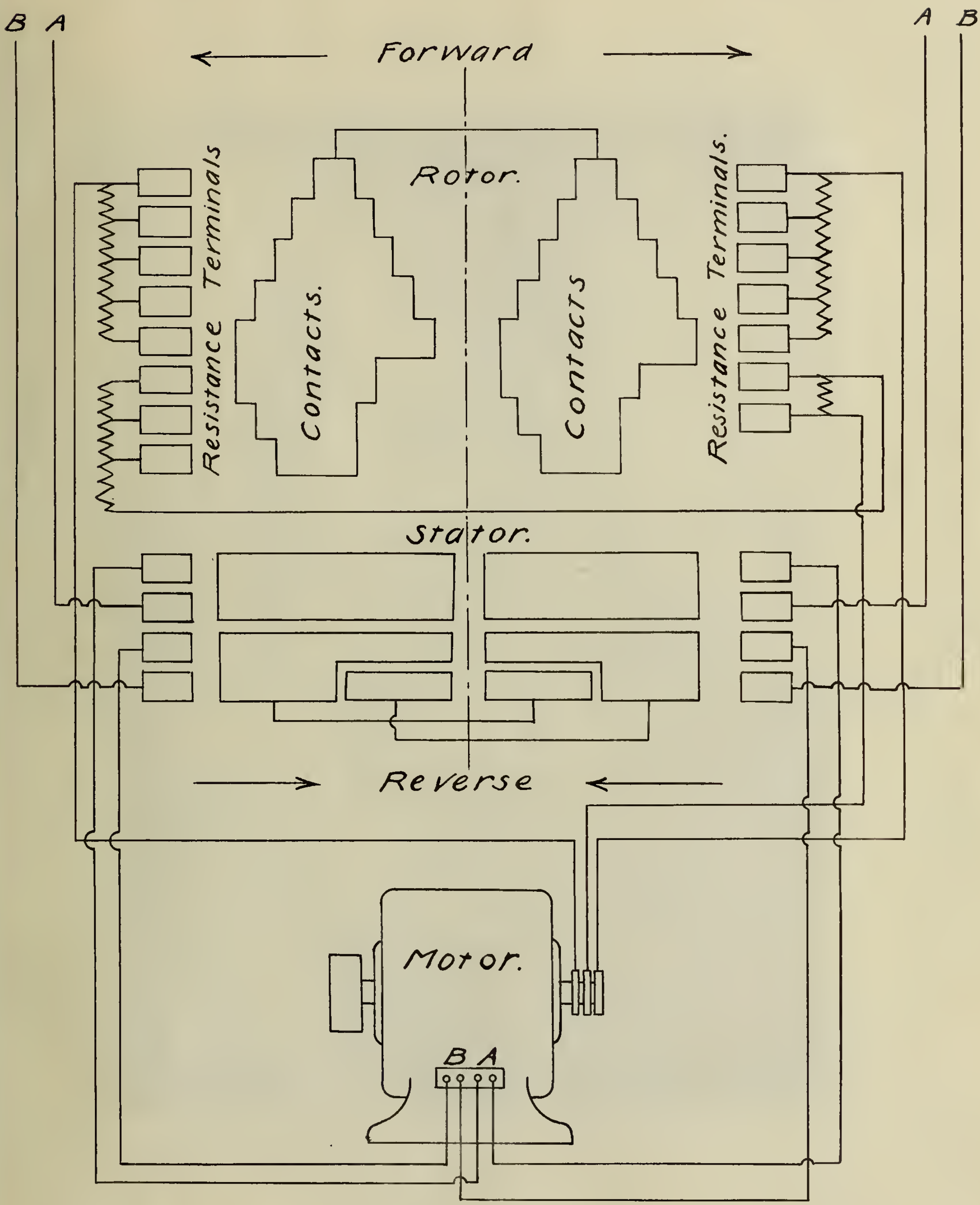
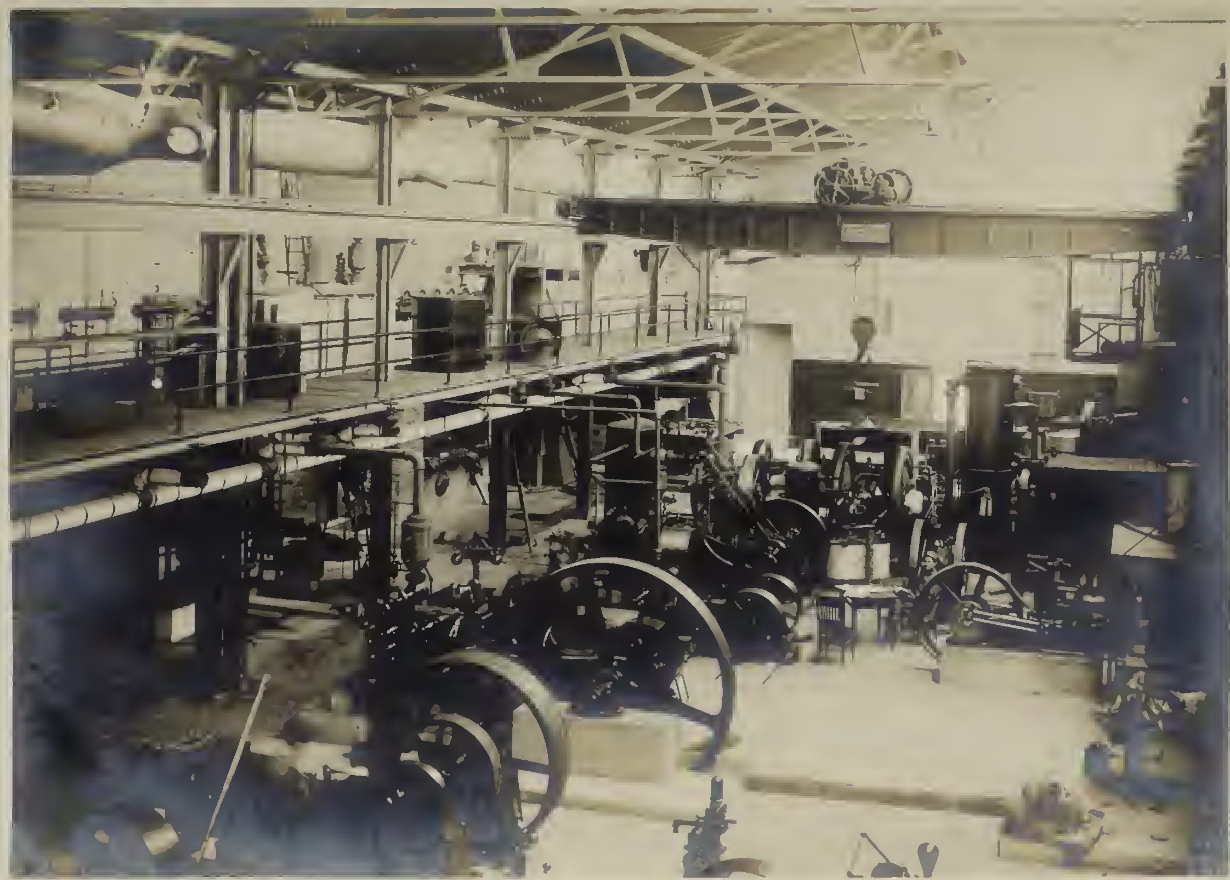


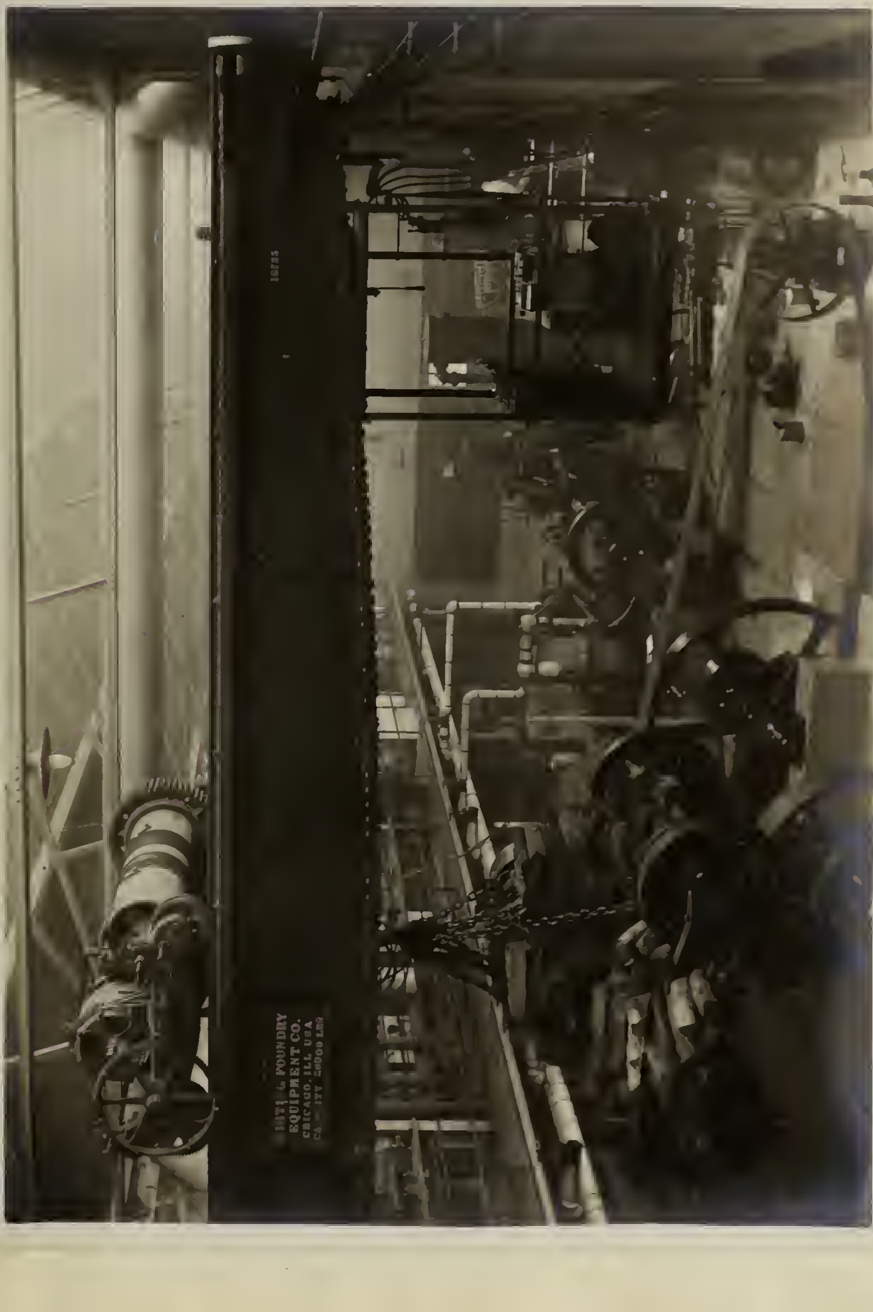
Diagram of Connections for Induction Motor and Controller.





General View of Crane.

Arrangement of Operator's Cab and Bridge Motor.



Crane With Load of 20000 Lbs.